

Wherefore, what is claimed is:

1. A computer-implemented process for correcting the exposure of improperly exposed pixels of an image, comprising using a computer to perform
5 the following process actions:

linearly expanding the dynamic range of the intensity levels of the image pixels so as to match the full dynamic intensity range available to a desired degree;

10 determining whether the linearly expanded intensity levels of the image pixels are evenly distributed; and

whenever the linearly expanded intensity levels of the pixels are determined not to be evenly distributed, applying a correction factor to the linearly expanded intensity level of each pixel in the image to produce a corrected intensity value for each pixel and evenly distributed intensity levels.

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2. The process of Claim 1, wherein the process action of linearly expanding the dynamic range of the intensity levels of the image pixels so as to match the full dynamic intensity range available to a desired degree, comprises an action of varying the degree to which intensity levels of the image pixels are
20 made to match the full dynamic intensity range available between expanding the dynamic range of the intensity levels to match the full dynamic intensity range available to no expansion at all, depending on the value of a safeness parameter.

25 3. The process of Claim 2, wherein the safeness parameter is prescribed.

4. The process of Claim 2, wherein the safeness parameter is user-specified.

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5. The process of Claim 1, wherein the process action of linearly expanding the dynamic range of the intensity levels of the image pixels, comprises the actions of:

5 computing a histogram of the intensity levels of the image pixels;
 computing the lowermost and uppermost intensity levels that are
consistent with the overall distribution of intensity levels in the image;
 computing new lowermost and uppermost intensity levels that span
the full dynamic intensity range available to a desired degree, and
 employing the originally computed lowermost and uppermost
10 intensity levels and the new lowermost and uppermost intensity levels to
establish a linear intensity correction transform that maps the original intensity
level of each pixel in the image to a linearly expanded intensity level;
 applying the linear intensity correction transform to each pixel of
the image.

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6. The process of Claim 5, wherein the process action of computing the lowermost and uppermost intensity levels which are consistent with the overall distribution of intensity levels in the image, comprises the actions of:

 computing the lowermost level as the level wherein,
20 the sum of the number of pixels exhibiting a level within a
prescribed range of levels extending from lowest level possible to the unknown
lowermost level, less one level, is less than the total number of pixels in the
image multiplied by a tolerance factor designed to eliminate the impact of noise
on the pixels intensity values, and
25 the sum of the number of pixels exhibiting a level within a
prescribed range of levels extending from lowest level possible to the unknown
lowermost level, is greater than or equal to the total number of pixels in the
image multiplied by the tolerance factor; and,
 computing the uppermost level as the level wherein,
30 the sum of the number of pixels exhibiting a level within a
prescribed range of levels extending from the unknown uppermost level to the

highest level possible is greater than or equal to the total number of pixels in the image multiplied by said tolerance factor, and

the sum of the number of pixels exhibiting a level within a prescribed range of levels extending from the unknown uppermost level, plus one level, to the highest level possible is less than the total number of pixels in the image multiplied by the tolerance factor.

7. The process of Claim 5, wherein the process action of linearly expanding the dynamic range of the intensity levels of the image pixels so as to match the full dynamic intensity range available to a desired degree, comprises an action of varying the degree to which intensity levels of the image pixels are made to match the full dynamic intensity range available between expanding the dynamic range of the intensity levels to match the full dynamic intensity range available to no expansion at all, depending on the value of a safeness parameter.

8. The process of Claim 7, wherein the process action of computing new lowermost and uppermost intensity levels that span the full dynamic intensity range available to a desired degree, comprises the actions of:

computing the new lowermost intensity level as $\hat{B} = (1 - \alpha)B$,

wherein B is the originally computed lowermost intensity level, \hat{B} is the new lowermost level and α is the safeness parameter which varies from 0 to 1; and

computing the new uppermost intensity level as

$\hat{T} = \alpha(L - 1) + (1 - \alpha)T$, wherein T is the originally computed uppermost intensity level, \hat{T} is the new uppermost level, L is the maximum possible intensity level and α is the safeness parameter.

9. The process of Claim 8, wherein the process action of employing the originally computed lowermost and uppermost intensity levels and the new lowermost and uppermost intensity levels to establish a linear intensity correction

transform, comprises an action of establish a linear intensity correction transform as $\hat{l} = al + b$, where, l is the original pixel intensity level, \hat{l} is the linearly expanded pixel intensity level, $a = (\hat{T} - \hat{B})/(T - B)$, and $b = (\hat{B}T - \hat{T}B)/(T - B)$.

5 10. The process of Claim 1, wherein the process action of determining whether the linearly expanded intensity levels of the image pixels are evenly distributed, comprises the actions of:

 computing a histogram from the linearly expanded pixel intensity levels;

10 computing a 50 percentile (i.e., median) intensity level from the linearly expanded pixel intensity level histogram as the level wherein,

 the sum of the number of pixels exhibiting a level within a prescribed range of levels extending from lowest level possible to the unknown median level, less one level, is less than the total number of pixels in the image multiplied by 0.5, and

15 the sum of the number of pixels exhibiting a level within a prescribed range of levels extending from lowest level possible to the unknown median level, is greater than or equal to the total number of pixels in the image multiplied by 0.5;

20 determining if the difference between the median intensity level and one half the maximum intensity level is less than or equal to the maximum intensity value multiplied by an intensity tolerance factor designed to compensate for the impact of noise on the pixels intensity levels; and

25 whenever it is determined that said difference is not less than or equal to said product, designating that the linearly expanded intensity levels of the image pixels are not evenly distributed.

 11. The process of Claim 1, wherein the process action of applying a correction factor to the linearly expanded intensity level of each pixel in the image to produce a corrected intensity value for each pixel and evenly distributed intensity levels, comprises the actions of:

computing a nonlinear gamma correction factor; and
applying the gamma correction factor to the linearly expanded pixel
intensity level of each pixel in the image.

5 12. The process of Claim 11, wherein the process action of computing
the nonlinear gamma correction factor, comprises the actions of:

 determining whether there is a significant peak in the lower side,
upper side, or both sides of the linearly expanded pixel intensity level histogram,
wherein a peak is considered significant if the number of pixels assigned to the
10 bins of the histogram around the peak pixel intensity level is larger than the
average;

 designating a significant peak determined to be in the lower side of
the histogram that exhibits the lowest intensity level as the low peak and
designating a significant peak determined to be in the upper side of the
15 histogram that exhibits the highest intensity level as the high peak;

 computing the 25 percentile, 50 percentile (i.e., median), and 75
percentile intensity levels from the linearly expanded pixel intensity level
histogram;

 establishing the gamma correction factor such that whenever the
20 median intensity level is greater than the maximum possible level multiplied by,
0.50 plus the intensity tolerance factor,

 the correction factor is set to 1 if the low peak is less than
one-eighth the maximum possible intensity level and the median intensity level is
greater than or equal to three-quarters the maximum possible intensity level,

25 the correction factor is set to the log of 0.125 divided by the
log of the low peak divided by the maximum possible intensity level if the low
peak is less than one-eighth the maximum possible intensity level and the
median intensity level is less than three-quarters the maximum possible intensity
level,

30 the correction factor is interpolated between 1 and a
prescribed maximum value if the low peak is greater or equal to one-eighth the

maximum possible intensity level and the median intensity level is greater than three-quarters the maximum possible intensity level, and the 75 percentile intensity level is between the maximum possible intensity level, and seven-eighths the maximum possible intensity level,

5 the correction factor is set to the log of 0.5 divided by the log of the median intensity level divided by the maximum possible intensity level if the low peak is greater or equal to one-eighth the maximum possible intensity level and the median intensity level is greater than three-quarters the maximum possible intensity level, and the 75 percentile intensity level is less than or equal

10 to seven-eighths the maximum possible intensity level, and

 otherwise the correction factor is set to 1; and

 establishing the gamma correction factor such that whenever the median intensity level is less than the maximum possible level multiplied by, 0.50 less the intensity tolerance factor,

15 the correction factor is set to 1 if the high peak is greater than seven-eighths the maximum possible intensity level,

 the correction factor is set to $\gamma = 1 - \frac{Q_{0.25}}{L/8}(1 - \gamma_{min})$ whenever

the 25 percentile intensity level is less than or equal to one-eighth the maximum possible intensity level, wherein γ is the correction factor, L is the maximum

20 possible intensity level, $Q_{0.25}$ is the 25 percentile intensity level and γ_{min} is a prescribed minimum correction factor value, and

 otherwise the correction factor is set to the log of 0.5 divided by the log of the median intensity level divided by the maximum possible intensity level, except that the factor is limited to at least the prescribed minimum

25 correction factor value.

13. The process of Claim 12, wherein the process action of determining whether there is a significant peak, comprises the actions of:

 determining if the sum of the number of pixels exhibiting a linearly

30 expanded intensity level within a prescribed range of levels extending from the

unknown peak intensity level, less a neighborhood size value which is equal to a prescribed number of levels, to the unknown peak level plus the neighborhood size value, is greater than or equal to the total number of pixels in the image multiplied by twice the neighborhood value plus 1 level, and divided by the
5 highest possible intensity level; and

whenever said sum is greater than or equal to the total number of pixels in the image multiplied by twice the neighborhood value plus 1 level, and divided by the highest possible intensity level, designating that the intensity level represents a significant peak.

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14. The process of Claim 12, wherein the process action of computing the 25 percentile intensity level, comprises an action of:

computing the 25 percentile intensity level as the level wherein,
the sum of the number of pixels exhibiting a level within a
15 prescribed range of levels extending from lowest level possible to the unknown 25 percentile intensity level, less one level, is less than the total number of pixels in the image multiplied by 0.25, and

the sum of the number of pixels exhibiting a level within a prescribed range of levels extending from lowest level possible to the unknown
20 25 percentile intensity level, is greater than or equal to the total number of pixels in the image multiplied by 0.25.

15. The process of Claim 12, wherein the process action of computing the 75 percentile intensity level, comprises an action of:

25 computing the 75 percentile intensity level as the level wherein,
the sum of the number of pixels exhibiting a level within a prescribed range of levels extending from lowest level possible to the unknown 75 percentile intensity level, less one level, is less than the total number of pixels in the image multiplied by 0.75, and

30 the sum of the number of pixels exhibiting a level within a prescribed range of levels extending from lowest level possible to the unknown

75 percentile intensity level, is greater than or equal to the total number of pixels in the image multiplied by 0.75.

16. The process of Claim 12, wherein the process action of
5 establishing the gamma correction factor by interpolating between 1 and the prescribed maximum value whenever the median intensity level is greater than the maximum possible level multiplied by 0.50 plus the intensity tolerance factor, and the 75 percentile intensity level is between the maximum possible intensity level, less one level and seven-eighths the maximum possible intensity level,
10 comprises an action of setting the correction factor to $\gamma = 1 + \frac{L - Q_{0.75}}{L/8} (\gamma_{\max} - 1)$
wherein γ is the correction factor, L is the maximum possible intensity level, $Q_{0.75}$ is the 75 percentile intensity level and γ_{\max} is the prescribed maximum correction factor value.

15 17. The process of Claim 16, wherein the prescribed maximum correction value ranges between about 1.2 and 2.5.

18. The process of Claim 17, wherein the prescribed maximum correction value is 1.5.

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19. The process of Claim 12, wherein the prescribed minimum correction value ranges between about 0.40 and 0.56.

20. The process of Claim 19, wherein the prescribed minimum
25 correction value is 0.48.

21. The process of Claim 11, wherein the process action of applying the gamma correction factor to the linearly expanded pixel intensity level of each pixel in the image, comprises an action of applying the gamma correction factor

to each linearly expanded pixel intensity value such that $\hat{l} = \left(\frac{l}{L-1} \right)^\gamma (L-1)$,

wherein \hat{l} is the corrected pixel intensity value, l is the linearly expanded pixel intensity value, γ is the correction factor, and L is the maximum possible intensity level.

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22. The process of Claim 21, further comprising a process action of, whenever the application of a gamma correction factor to the linearly expanded intensity level of each pixel in the image results in an overall brightening of the image, boosting the color saturation levels of each color channel of each pixel of the image by a desired amount.

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23. The process of Claim 22, wherein the process action of boosting the color saturation levels of each color channel of each pixel of the image by a desired amount whenever the application of a gamma correction factor to the linearly expanded intensity level of each pixel in the image results in an overall brightening of the image, comprises the actions of:

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determining if the gamma correction factor is less than one indicating the image is brightened by its application; and

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whenever the correction factor is less than one, boosting the color saturation level of each color channel of each pixel in the image by $\frac{1-\gamma}{1-\gamma_{\min}} \times 1.25$,

wherein γ is the correction factor and γ_{\min} is a prescribed minimum correction factor value.

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24. A system for correcting the exposure of improperly exposed pixels of an image, comprising:

a general purpose computing device;

a computer program comprising program modules executable by the computing device, wherein the computing device is directed by the program modules of the computer program to,

compute a histogram of the intensity levels of the image
pixels,

compute the lowermost and uppermost intensity levels that
are consistent with the overall distribution of intensity levels in the image,

5 compute new lowermost and uppermost intensity levels that
span the full dynamic intensity range available to a desired degree, and

employ the originally computed lowermost and uppermost
intensity levels and the new lowermost and uppermost intensity levels to
establish a linear intensity correction transform that maps the original intensity
10 level of each pixel in the image to a linearly expanded intensity level,

apply the linear intensity correction transform to each pixel of
the image,

determine whether the linearly expanded intensity levels of
the image pixels are evenly distributed, and

15 whenever the linearly expanded intensity levels of the pixels
are determined not to be evenly distributed, employing a gamma correction
factor to the linearly expanded intensity level of each pixel in the image to
produce a corrected intensity value for each pixel.

20 25. The system of Claim 24, further comprising a program module for,
whenever the application of a gamma correction factor to the linearly expanded
intensity level of each pixel in the image results in an overall brightening of the
image, boosting the color saturation levels of each color channel of each pixel of
the image by a desired amount.

25 26. The system of Claim 25, wherein the program module for boosting
the color saturation levels of each color channel of each pixel of the image by a
desired amount, comprises an action of varying the degree to which the color
saturation levels of the image pixels are boosted between about 25 percent to
30 less than 1 percent, in proportion to the degree of brightening.

27. The system of Claim 24, wherein the program module for employing a gamma correction factor to the linearly expanded intensity level of each pixel in the image to produce a corrected intensity value for each pixel, comprises sub-modules for:

- 5 computing a nonlinear gamma correction factor; and
- applying the gamma correction factor to the linearly expanded pixel intensity level of each pixel in the image.

28. The system of Claim 27, wherein the sub-module for computing the nonlinear gamma correction factor, comprises sub-modules for:

- 10 determining whether there is a significant peak in the lower side, upper side, or both sides of the linearly expanded pixel intensity level histogram, wherein a peak is considered significant if the number of pixels assigned to the bins of the histogram around the peak pixel intensity level is larger than the
- 15 average;

- designating a significant peak determined to be in the lower side of the histogram that exhibits the lowest intensity level as the low peak and
- designating a significant peak determined to be in the upper side of the histogram that exhibits the highest intensity level as the high peak;

- 20 computing the 25 percentile, 50 percentile (i.e. median), and 75 percentile intensity levels from the linearly expanded pixel intensity level histogram;

- establishing the gamma correction factor such that whenever the median intensity level is greater than the maximum possible level multiplied by,
- 25 0.50 plus the intensity tolerance factor,

- the correction factor is set to 1 if the low peak is less than one-eighth the maximum possible intensity level and the median intensity level is greater than or equal to three-quarters the maximum possible intensity level,

- the correction factor is set to the log of 0.125 divided by the
- 30 log of the low peak divided by the maximum possible intensity level if the low peak is less than one-eighth the maximum possible intensity level and the

median intensity level is less than three-quarters the maximum possible intensity level,

the correction factor is interpolated between 1 and a prescribed maximum value if the low peak is greater or equal to one-eighth the maximum possible intensity level and the median intensity level is greater than three-quarters the maximum possible intensity level, and the 75 percentile intensity level is between the maximum possible intensity level, and seven-eighths the maximum possible intensity level,

the correction factor is set to the log of 0.55 divided by the log of the median intensity level divided by the maximum possible intensity level if the low peak is greater or equal to one-eighth the maximum possible intensity level and the median intensity level is greater than three-quarters the maximum possible intensity level, and the 75 percentile intensity level is less than or equal to seven-eighths the maximum possible intensity level, and

otherwise the correction factor is set to 1; and

establishing the gamma correction factor such that whenever the median intensity level is less than the maximum possible level multiplied by, 0.50 less the intensity tolerance factor,

the correction factor is set to 1 if the high peak is greater than seven-eighths the maximum possible intensity level,

the correction factor is set to $\gamma = 1 - \frac{Q_{0.25}}{L/8} (1 - \gamma_{\min})$ whenever the 25 percentile intensity level is less than or equal to one-eighth the maximum possible intensity level, wherein γ is the correction factor, L is the maximum possible intensity level, $Q_{0.25}$ is the 25 percentile intensity level and γ_{\min} is a prescribed minimum correction factor value, and

otherwise the correction factor is set to the log of 0.5 divided by the log of the median intensity level divided by the maximum possible

intensity level, except that the factor is limited to at least the prescribed minimum correction factor value.

29. The system of Claim 27, wherein the sub-module for applying the gamma correction factor to the linearly expanded pixel intensity level of each pixel in the image, comprises an action of applying the gamma correction factor to each linearly expanded pixel intensity value such that $\hat{l} = \left(\frac{l}{L-1} \right)^\gamma (L-1)$, wherein \hat{l} is the corrected pixel intensity value, l is the linearly expanded pixel intensity value, γ is the correction factor, and L is the maximum possible intensity level.

30. A computer-readable medium having computer-executable instructions for performing the process actions recited in Claim 1.